

# Transition from Research to Operations by the NCEP/EMC Land Team

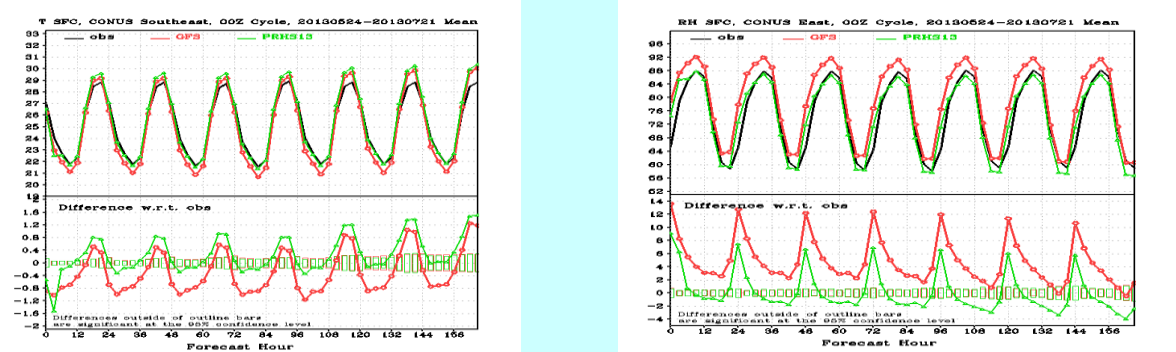
EMC Land-Hydrology Team: Michael Ek, Jesse Meng, Rongqian Yang, Helin Wei, Youlong Xia, Yihua Wu, Weizhong Zheng, Jiarui Dong, Roshan Shrestha

## Global Forecast System (GFS) /Gridpoint Statistical Interpolation (GSI)

The land surface interacts with the atmosphere across many time scales including the medium-range NWP. Accurate representation of the land surface is very important because it provides the lower boundary condition for the atmospheric model. Working with the colleagues from University of Arizona, Boston University, JCSDA, and NCAR, many land physics advances and new land data sets have been transitioned from research to operations during the last decade.

- the reformulation of surface roughness length for heat was implemented in the operational GFS. (Univ. of Arizona)
- The refinement of land-atmosphere coupling strength was tested in the parallel GFS. (NCAR)
- The new high-resolution MODIS-based LSC data was tested in the parallel GFS. (Univ. of Arizon, Boston Univ.)
- New snow physics to address Nosh early snowmelt bias were tested in the parallel GFS. (Univ. of Arizona)
- The microwave land surface emissivity calculation was improved and implemented in the new released CRTM 2.1 version. (JCSDA)

Surface 2-m T and Rh improvement after land upgrades in the current parallel GFS



Satellite radiance measurements in various spectral channels are assimilated as radiances through the JCSDA CRTM on the NCEP GSI, which requires the CRTM to calculate model brightness temperature (Tb) with input of model atmosphere profiles and surface parameters. In particular, for surface sensitive channels, Tb largely depends on surface parameters such as land surface skin temperature (LST) and soil moisture, and surface emissivity (infrared and microwave). Therefore, in order to improve radiance data assimilation, we have to improve not only surface emissivity calculation but also model surface parameters simulation. The new roughness length formulations which reduce GFS LST cold bias were implemented in operational GFS in May 2011. The microwave emissivity calculation with more accurate land surface parameters, canopy optical parameters and alternative dielectric constant calculation, was improved and implemented in CRTM v2.1.

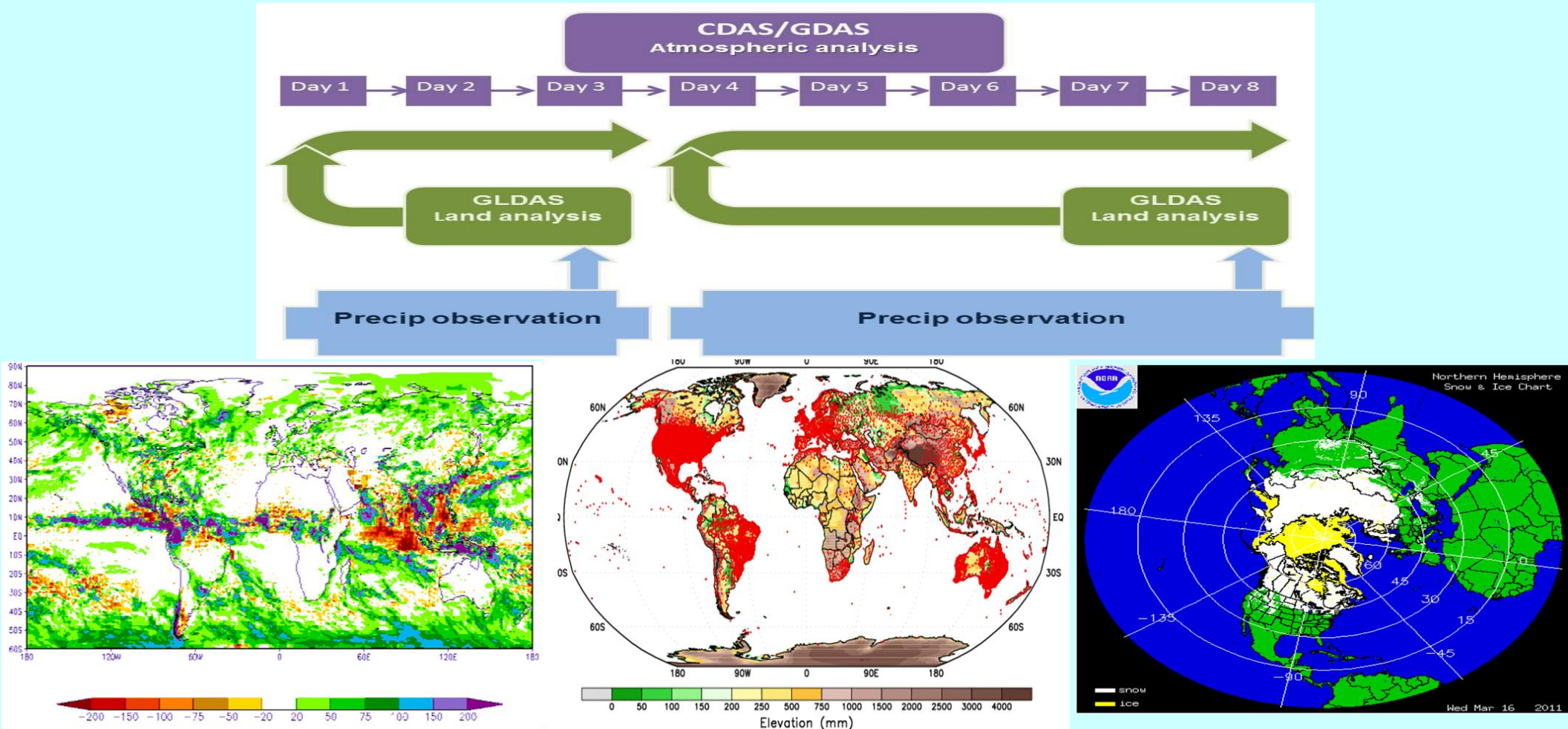
## Abstract

One of the main NCEP/EMC missions is to transition operational forecast models from research to operation. EMC operates numerical forecast systems for a wide range of scale from short-time (NAM), medium-range(GFS) to seasonal and climate (CFS). In collaboration with its partners, the NCEP/EMC land team has been actively transitioning the land surface upgrades including physics and the new dataset from research community to the NCEP/EMC operational models:

- (1) Working with the colleagues from University of Arizona and JCSDA, the reformulation of surface roughness length for heat was implemented in the operational GFS to reduce daytime LST cold bias over desert and arid regions in the warm season, which results in larger amounts of satellite data accepted in the data assimilation over land in the GSI/CRTM. The microwave land surface emissivity calculation was improved and implemented in the new released CRTM 2.1 version. The new high-resolution MODIS-based LSC data was used in the operational NAM.
- (2) Working with international colleagues on fresh lake modeling, lake surface temperature climatology for the North America has been created, and is in validation stage, and will be implemented in NAN operation forecast.
- (3) Under the support from the current CPO/MAPP program on the transition of latest development on Noah LSM into operation, the Noah LSM with Multiple-Parameterization (MP) options is being tested in the CFS. The CFS/Noah MP provides a prototype for the next generation of physics-based ensemble approach for seasonal prediction. The implementation has been in close collaborations with the Noah MP development team members from U. Texas at Austin, U. Arizona at Tucson, and NCAR.
- (4) Working with NASA and the other external collaborators, three Land Data Assimilation Systems (LDAS) have been developed to support a wide range of climate, weather, and hydrometeorology applications:
  - a) The purpose of NLDAS is to provide initial land states to regional numerical models to enhance regional weather and climate prediction skills, and to support CPC monthly drought briefing and the U.S. National Integrated Drought Information System (NIDIS). The operational implementation of NLDAS monitoring/analysis component will take place next year.
  - b) The purpose of GLDAS is to provide enhanced initial land states to the NCEP CFS to improve global seasonal climate simulation and prediction, and to the NCEP GFS to improve global medium range weather prediction, and generate hydrometeorological reanalysis products to support users.
  - c) HRAP-NLDAS for long-term and near real-time high-resolution (~4 km) hydrometeorological products to support hydrological research and application at NWS River Forecast Centers and OHD, as well as furthering their support of HTB.
- (5) Working with the colleagues from NESDIS and NASA, the testing of assimilating the NESDIS operational satellite land products such as skin temperature, snow, and soil moisture has begun. The LIS DA tool will be used to ingest these satellite land products to upgrade the land surface initial conditions in GFS and NAM. The NCEP/EMC land team is also involves in transition-from-operations to research. We actively participate some international model inter-comparison projects such as PALS(Land Model Benchmarking) and DICE(Diurnal land/atmosphere coupling experiment) to improve NCEP weather and climate model components.

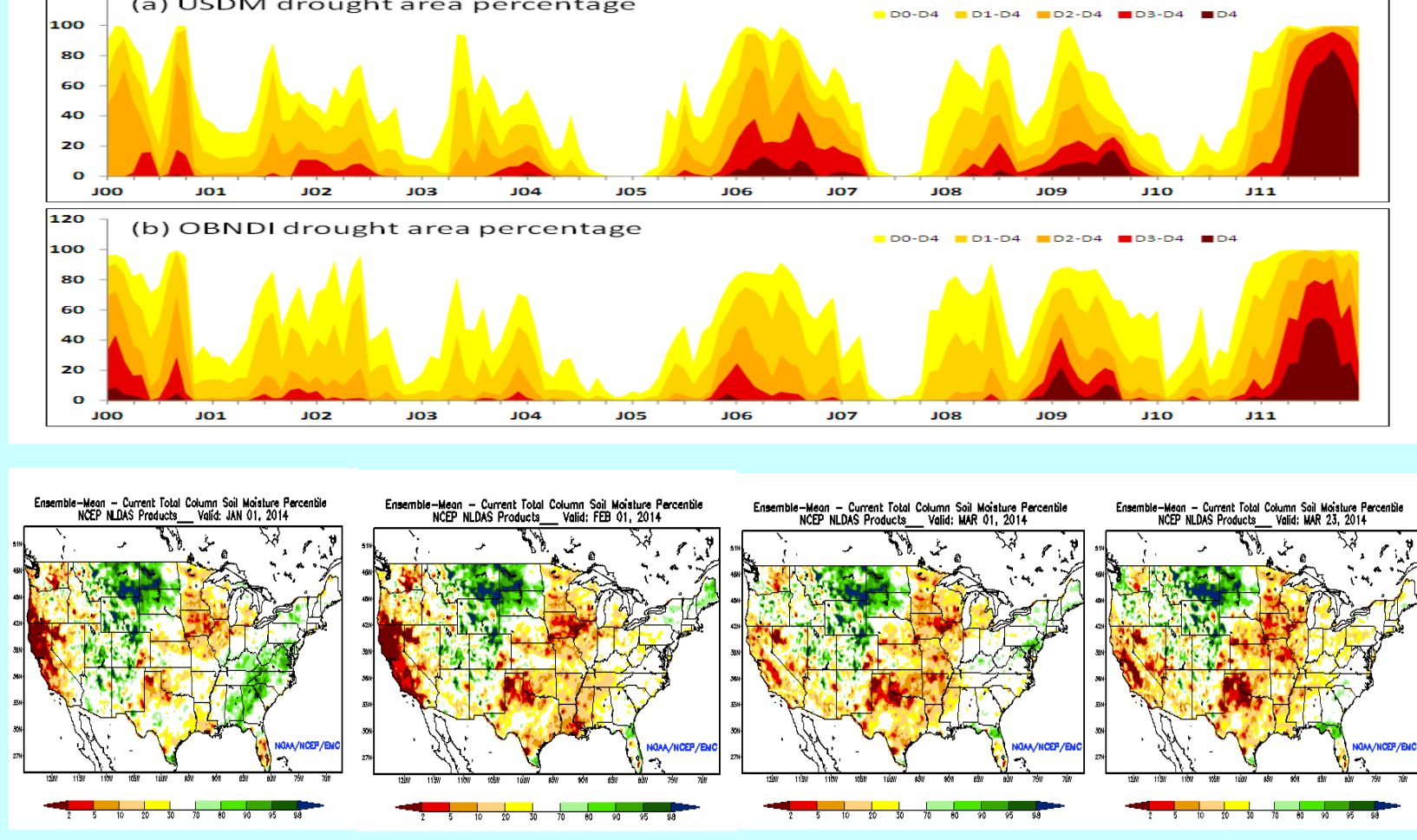
## Global Land Data Assimilation System (GLDAS)

GLDAS is implemented in the NCEP operation to support the NCEP operational Climate Forecast System (CFSv2) for seasonal climate prediction and the Global Forecast System (GFS) for mid-range weather prediction. Accurate initialization of land surface states is critical in climate and weather prediction systems because of their regulation of water and energy fluxes between the land surface and atmosphere over a variety of spatial and temporal scales. Since measurements of many land surface states are generally not available on global scales, traditional coupled land-atmosphere prediction systems rely on their land surface models to predict the land surface states and fluxes. It is widely acknowledged that bias in the land surface forcing predicted by the atmospheric model, particularly precipitation, may lead to nontrivial bias in predicted land surface states and fluxes. In order to provide enhanced land surface states for operational prediction systems, the NCEP GLDAS is implemented using the NASA Land Information System (LIS). Global observed precipitation is used as direct forcing to drive GLDAS/LIS. Global observed snow cover and depth are used to constrain the predicted snow field. The NCEP GLDAS has been used in the CFS Reanalysis and Reforecast project (CFSRR) to execute the land analysis and to provide land surface initial conditions to the reforecast experiments. The coupled CFSRR prediction and assimilation system was transitioned into NCEP operations for seasonal climate prediction (CFSv2). Currently, GLDAS is also under testing as part of the development of the coupled NCEP GFS Data Assimilation System (GDAS), anticipating improving the GFS mid-range weather prediction.



## North American Land Data Assimilation System (NLDAS)

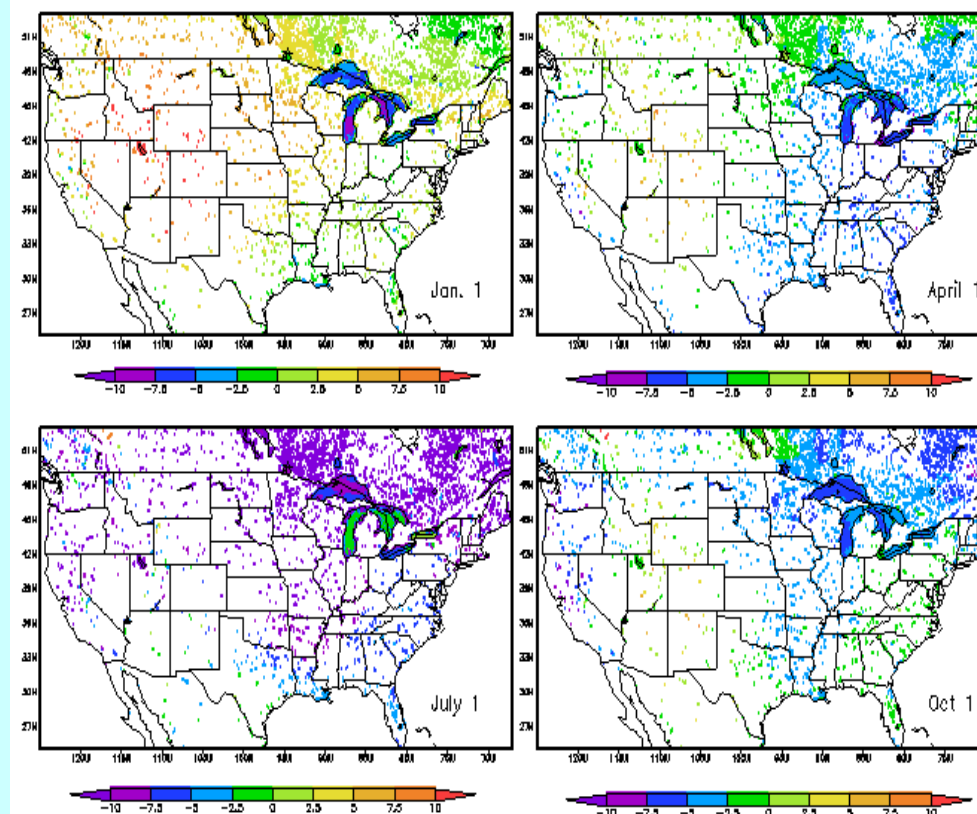
Currently NLDAS is a quasi-operational system at NCEP to support U.S. operational drought monitoring and seasonal hydraulic prediction (e.g., National Integrated Drought Information System). This system includes two components: (1) Analysis/Monitoring mode and (2) Seasonal Forecast mode. The monitoring model consists of a retrospective 29-year (79-08) historical execution and a near real-time daily update execution using four land surface models on a common 1/8th degree grid using common hourly land surface forcing. The non-precipitation surface forcing is derived from the NCEP North American Regional Reanalysis (NARR). The precipitation forcing is anchored to daily gauge-only precipitation over Continental United States that applies Parameter-elevation Regressions on Independent Slopes Model corrections. The NARR-based surface downward solar radiation is bias-corrected using seven years (1997-2004) of satellite-derived solar radiation retrievals. Near real-time land states and water fluxes of each of the four models from daily executions are depicted as anomalies and percentiles with respect to their own model climatology, shown at the "NLDAS Drought" tab of the NLDAS website. NLDAS products are directly provided to the U.S. Drought Monitor author group daily. NLDAS is being implemented in NCEP operations this year. The NCEP/EMC NLDAS team is collaborating with the NASA to add its Land Information System to the current NLDAS system to allow assimilation of remotely-sensed data and in-situ observations. The forecast mode using three methods: (1) Ensemble Streamflow Prediction (ESP), (2) CPC Seasonal Outlook, and (3) CFSv2 dynamical approach to generate land surface model forcing (e.g., precipitation, air temperature, wind speed) by using observed precipitation and Bayesian algorithm. We use these forcings to run VIC model to generate 1-6 month ensemble forecast products to support CPC monthly drought briefing and seasonal drought outlook. The system is run one time in the beginning of each month and the products and images are uploaded to NLDAS website.



## North American Mesoscale Forecast System (NAM)

There are about 5 million lakes with a surface area greater than 0.1 km<sup>2</sup> and countless smaller lakes and ponds on the earth. More than 60 percent of the world's lakes are in North America, and most lie at higher latitudes. Lakes have important impacts on climate and weather. Lake-effect precipitation occurs on the downwind coastal area of many medium to large size temperate lakes in winter. Lakes affect the air temperature even on the small scale. However, a large number of small to medium lakes are indistinguishable as sub-grid scale features in most of numerical weather predictions models (NWP), and their effects are either ignored or crudely parameterized. As the horizontal resolution increases, lakes are becoming resolved features, and their effects become apparent and should be taken into account. Based on model performance and computational expensive, the Flake model is chosen to simulate lake water surface temperature for USCONUS. Long term meteorological daily means for years 1979 – 2000 from the NCEP North American Regional Reanalysis (NARR) are used as driving forcing. Lake depth is from the 1 km Lake depth data set developed by Kourzeneva (2009). The simulated lake surface temperature was compared with the daily, high-resolution, real-time, global, sea surface

temperature (HR\_RTG\_SST) analysis. Compared with HR\_RTG\_SST, the Flake has larger annual variation, and is warmer in warm seasons, colder in cold seasons (the Great Lakes are exceptions). In cold seasons, the difference between Flake and HR\_RTG\_SST is within 5 degrees. In warmer seasons, the difference is larger than 5 degrees (the Great Lakes have the opposite pattern). Flake-simulated lake surface temperature is closer to lake measurements than HR\_RTG\_SST. The differences between HR\_RTG\_SST and Flake Surface temperature for January 1<sup>st</sup>, April 1<sup>st</sup>, July 1<sup>st</sup>, and October 1<sup>st</sup> are shown in the figure below.



## High Resolution NLDAS

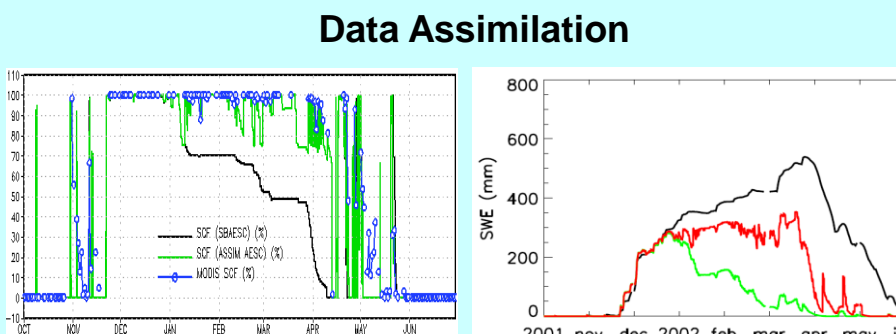
This MAPP-funded project centers on supporting NOAA/NCEP/EMC's and NOAA/NWS/OHD's operational hydrological and land surface modeling missions, as well as furthering their support of the *National Integrated Drought Information System (NIDIS)*, NOAA Hydrology Test Bed, and the NOAA Climate Test Bed. New capabilities resulting from this joint NOAA EMC/OHD/CPC effort will allow for the execution of enhanced Noah and Sacramento Heat Transfer (SAC-HTET) models on the 4km HRAP grid over the Continental United States (CONUS) over a 33-year period using NLDAS2 forcing data. Enhancements will impact all stages of modeling operations and will include improved downscaled forcing data, spin-up strategies, data assimilation modules, model physics, and model validation procedures.

### Model Support-Related Improvements

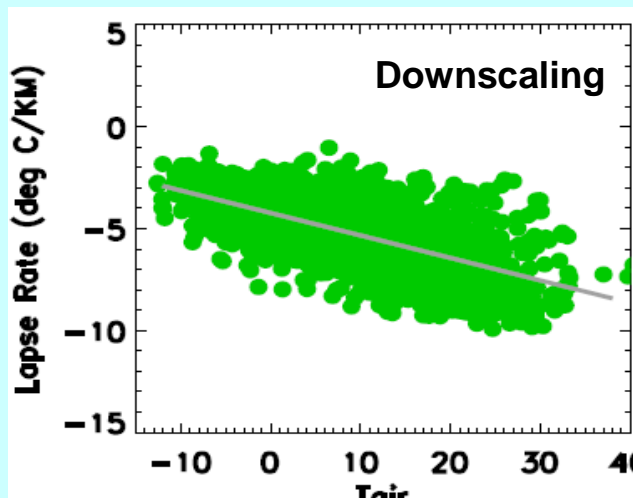
- Improved downscaling of 1/8th degree NLDAS forcing to 4km HRAP grid
- Enhanced spin-up strategies for retrospective and real-time simulations

### Model Component Improvements

- Improved snow assimilation modules for Noah and SAC-HT/Snow17
- High-resolution routing capability for Noah and SAC-HT in LIS
- Testing of NOAA ET physics in SAC-HT (SAC-HTET)
- Testing of improved sub-surface runoff modeling in SAC-HT
- Integration of dynamic parameter calculation module into Snow17
- Enhanced Noah bundle upgrades

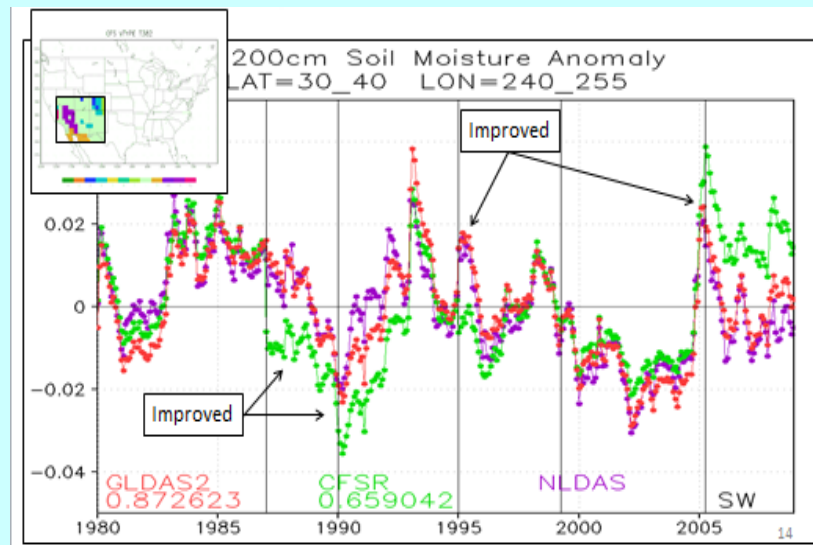


The statistical linear regression equation is spatially and temporally independent, with air temperature as the only input variable. The approach is thus well-suited for producing time- and space-varying lapse rates, and would require minimal resources to implement in the downscaling software which typically support land surface and hydrologic modeling activities



The relationship between the lapse rate and air temperature derived from 60 grid boxes with 5 or above in-situ stations available for each month averaged over 1991-2012.

Comparison of fractional snow cover between the MODIS (blue circle), the open loop simulation (black line) and the assimilated simulation (green line) (left), and comparison of snow water equivalent between the open loop simulation (green), the assimilation simulation (red) and the in-situ measurement (black) averaged over all SNOTEL sites in the study region (right).



CFSR run with six simultaneous "streams" (separate runs) over the 32-year period (1979-2010) with the issue of discontinuity of evolving land states.

A sufficient spin-up process for each single stream is required to maintain the continuity of land states.

## PALS & DICE

PALS (Protocol for the Analysis of Land Surface models) is a web application for evaluating land surface models and the data sets used to test them. It provides driving and evaluation data for particular modeling experiments as well as a wide range of diagnostic performance measures once model output created using these data is uploaded. PALS is a useful tool for benchmarking both individual studies and community experiments. PALS is used to compare five land surface models (Noah, Jules, Cable, Cable\_Sli and ColaSSIB) at 20 flux tower sites against 5 benchmarks: (1) Manabe bucket model, (2) Penman-Monteith implementation, (3) Out-of-sample (other sites only) linear regression of flux against downward shortwave (SWdown), (4) As in (3), but multiple linear regression of flux against SWdown and air temperature (Tair), (5) As in (3), but 27-node clustering+regression against SWdown, Tair and relative humidity.

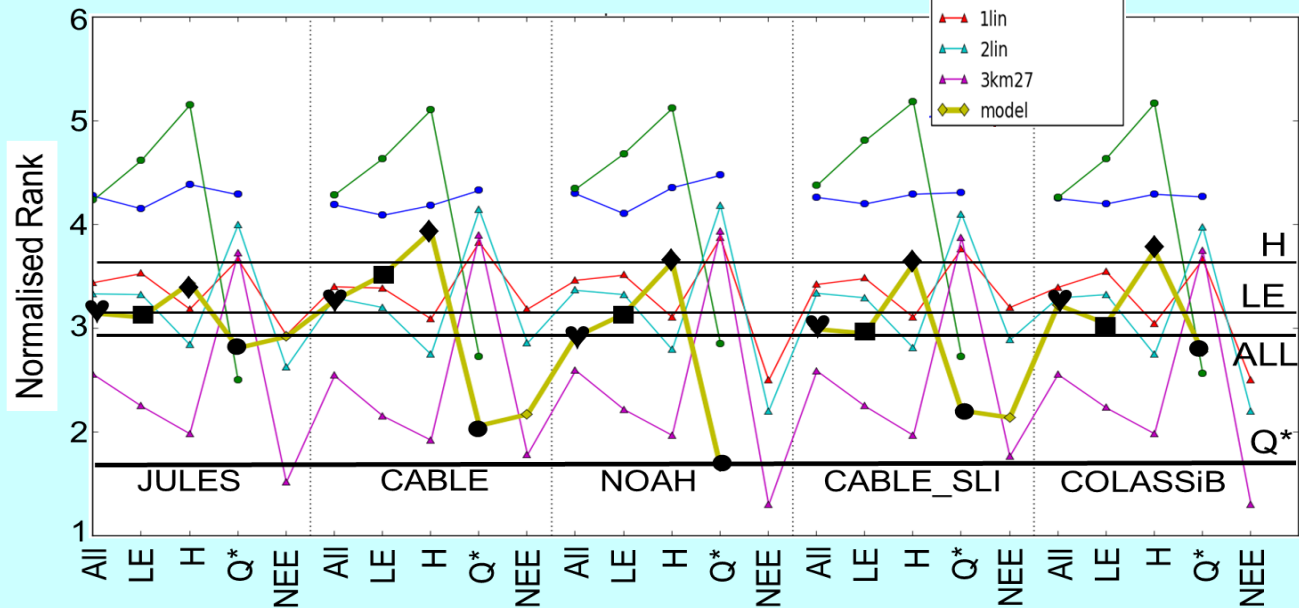
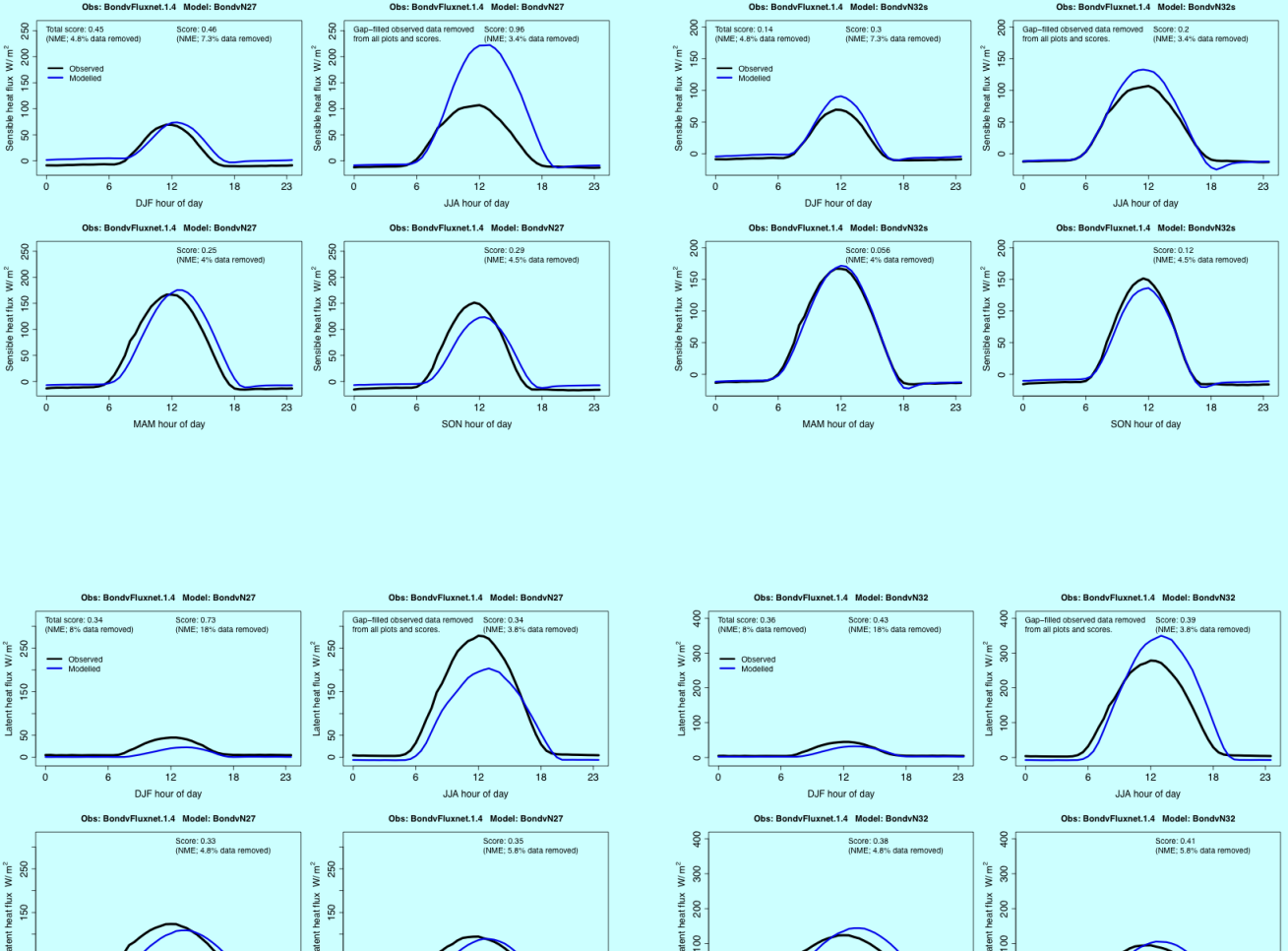


Figure. Results from five land surface models (Noah, Jules, Cable, Cable\_Sli and ColaSSIB) against benchmarks.

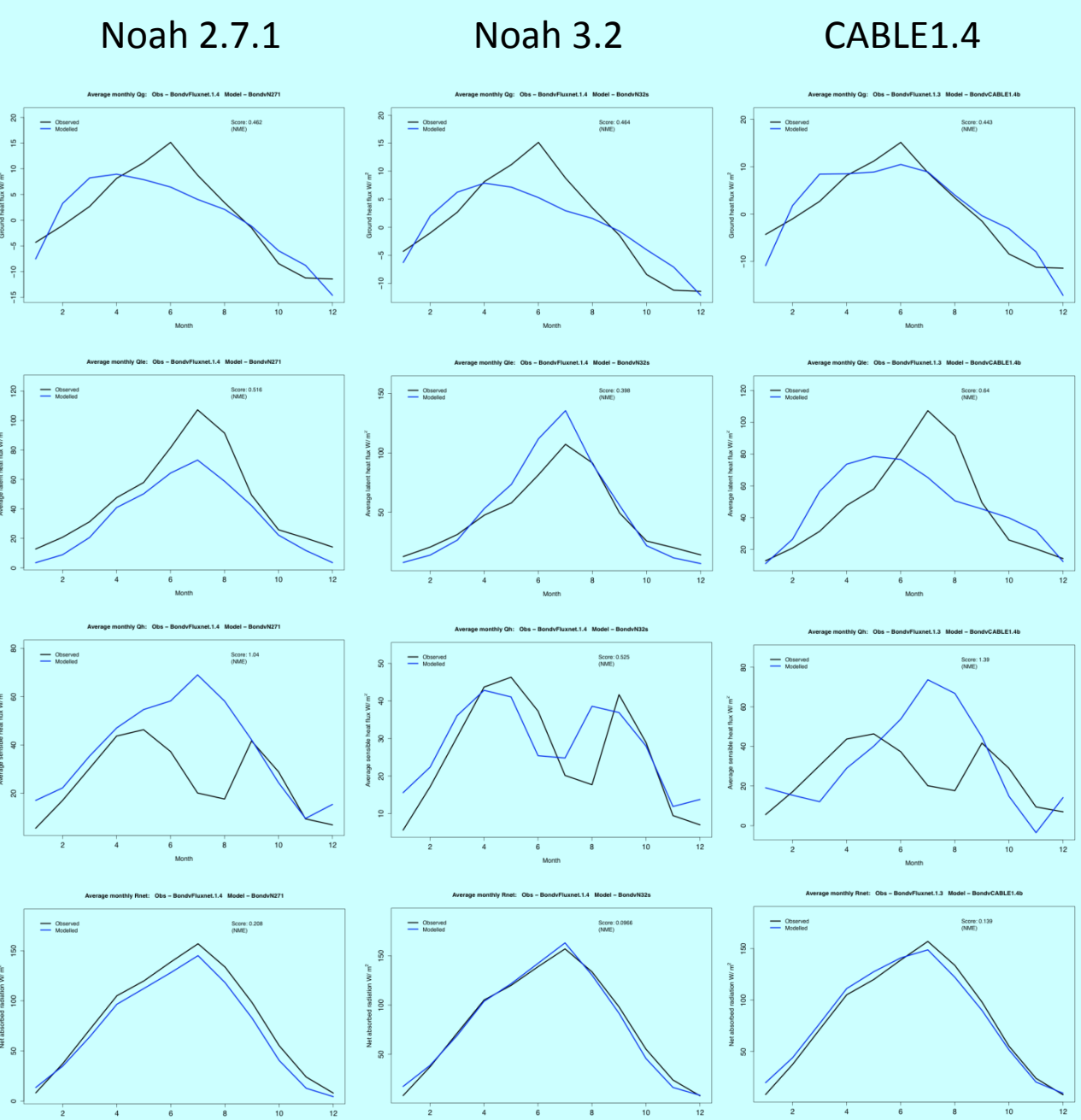
Noah passed all five benchmark tests for net radiation (Q\*), and passed four benchmark tests for ALL fluxes and latent heat flux, but didn't pass the "3km27" regression benchmark test. Sensible heat flux output from the model just passes the two simple benchmark tests (Manabe bucket and Penman-Monteith), but didn't pass all three regression benchmarks. Comparing results to other land surface models, Noah did a better job in estimating net radiation (Q\*) and ALL fluxes pooled together, and did a comparable job in estimating latent heat and sensible heat fluxes. Because Noah did the best job in estimating the net radiation, it provides a strong platform for accurately estimating the latent and sensible heat fluxes by correctly partitioning them through future proposed improvements.

Later versions of Noah LSM include improvements and bug-fixes. A comparative study of Noah 3.2 and Noah 2.7.1 is conducted at several approximately 40 FLUXNET stations located across the world using the forcings from PALS experiment project.



Comparison of Seasonal Diurnal Cycle of Latent heat flux from Noah 2.7.1 (left) and Noah 3.2 (right).

Seasonal and diurnal analyses of fluxes are investigated. Improvements are noted in sensible heat simulation in version 3.2 compared to version 2.7.1 at many locations but the improvements are not consistent over all locations and all vegetation types. The summer-season improvement in sensible heat flux is notably significant in cropland. It is noted that systematic low bias problem in latent heat flux in version 2.7.1 are over-corrected in later versions of the Noah models, which has contributed to high biases, particularly in summer season daytime fluxes.



Comparison of Annual Cycle fluxes from Noah 2.7.1 (left), Noah 3.2 (center), and CABLE1.4 (right).

PALS also allows us to compare Noah LSM with other models participating in the study. Illustrated above is a case, in which, Noah 3.2 is found to have better annual cycles of Sensible and Latent heat fluxes. CABLE is slightly better in simulating ground heat flux. The net radiation of Noah 3.2 is also improved. Improvement in summer season sensible heat flux is significant.

DICE (Diurnal Land/Atmosphere Coupling Experiment) is an international experiment designed to identify and understand the interaction and feedback between the land and atmospheric boundary layer. It assesses the impact of land-atmosphere feedback by first assessing the land and single-column atmosphere models separately, constrained by observational data, and then identifying changes due to coupling. In this presentation, the NCEP single column model (SCM) coupled with Noah land surface model (LSM) is examined with the DICE approach. Following the DICE project outlines, the observed atmospheric forcing was first used to drive the off-line Noah LSM, then the observed surface fluxes was used to drive the SCM, and finally the SCM coupled with the Noah LSM was run to investigate the land-atmosphere feedback. At the last stage, the Noah LSM was run with the set of atmospheric forcing derived by each of other SCMs, and the NCEP SCM was run with the set of surface fluxes derived by each of other LSMs.

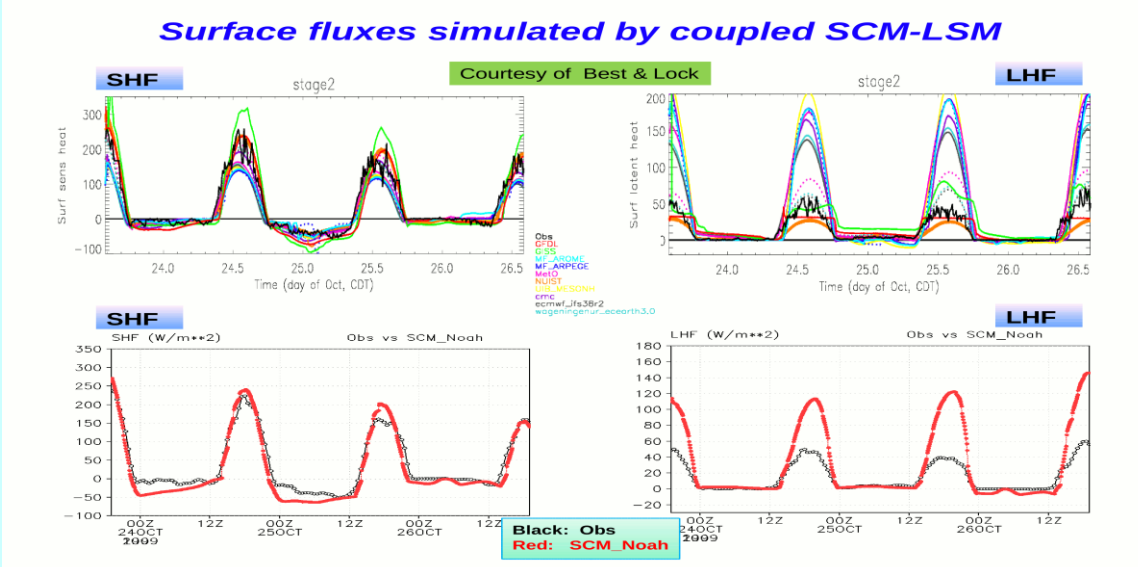


Figure. Simulated surface fluxes by NCEP SCM-LSM and other various models

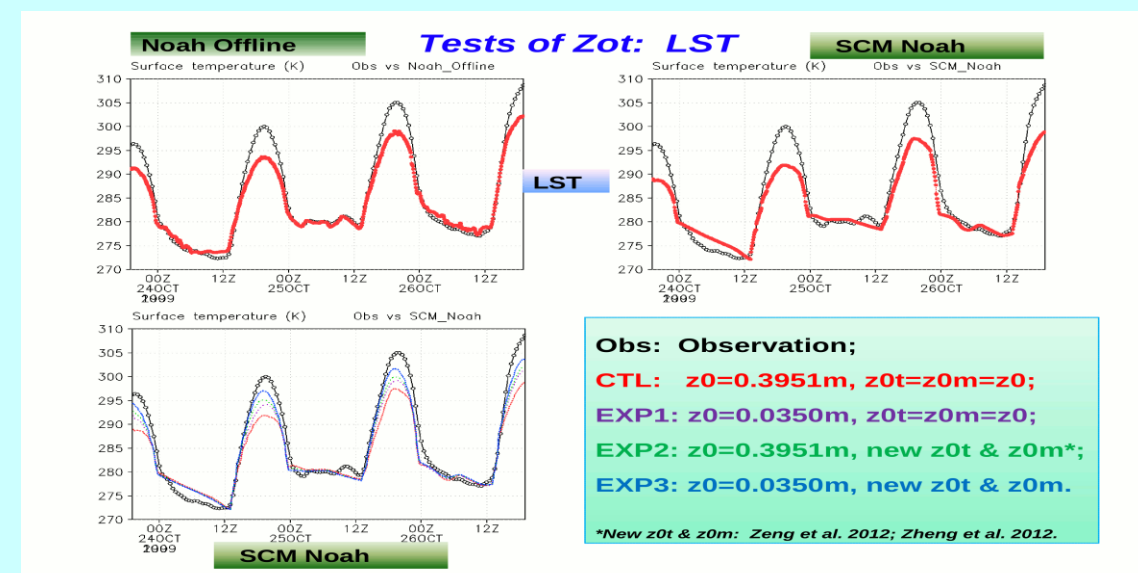


Figure. Tests of new momentum and thermal roughness lengths.